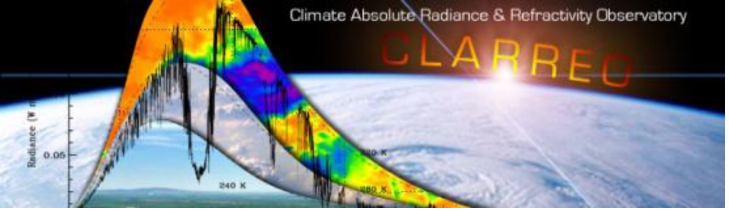


Science Definition Support for the CLARREO RS Instrument and Measurements

Jim Butler and Jack Xiong

NASA/GSFC, Greenbelt, MD 20771

CLARREO Science Team Meeting
National Institute of Aerospace, Hampton, VA, May 17-19, 2011

Outline

- Introduction
- Proposed Science Definition Support
- Approaches
- Timeline and Deliverables
- Summary

Introduction

- CLARREO Mission
  - Addresses the need to observe climate change and to determine the accuracy of its projections
    - Enables highly accurate and SI traceable decadal change observations
    - Provides reference intercalibration of temporally and spatially coincident measurements from other on-orbit sensors
- CLARREO Science Definition Team (SDT)
  - Supports science definition activities and planning for the mission
    - Refines and prioritizes scientific goals and the measurement requirements and accuracies
    - Defines geophysical products and data sets to be provided by the mission
    - Provides guidance for mission cal/val plan, algorithm development, data processing system, and the use of CLARREO data for testing and improving climate projections

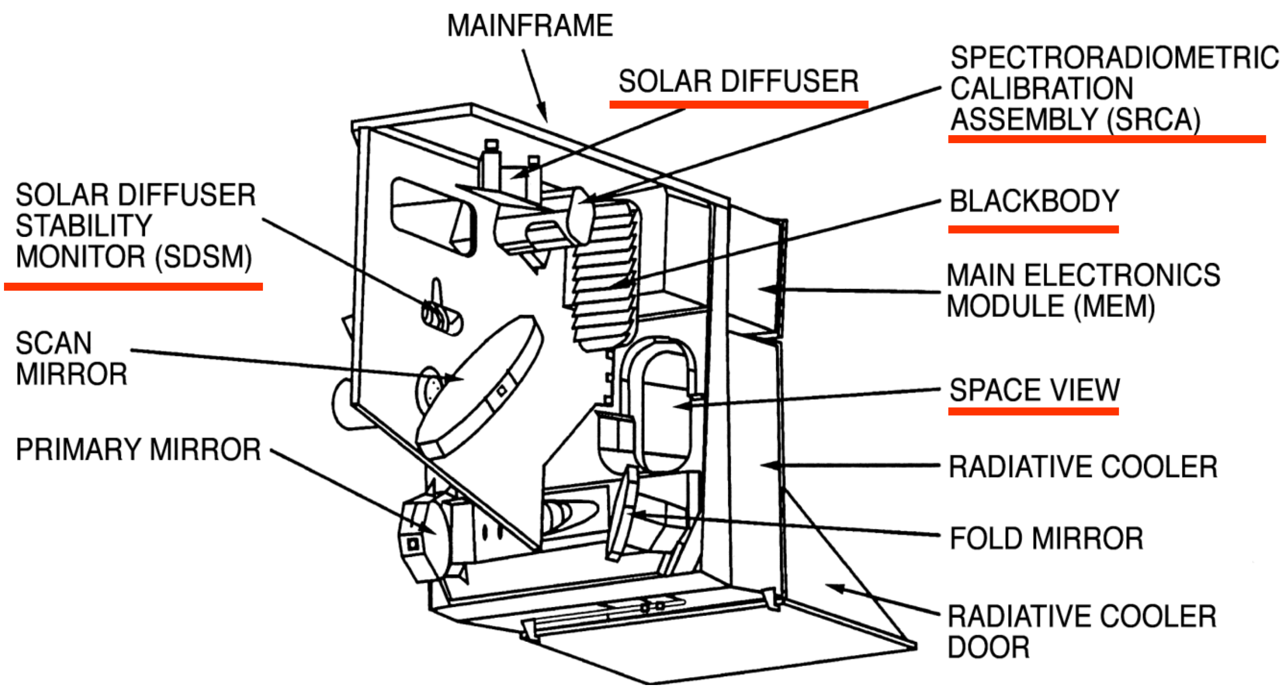
Proposed Science Definition Support

- Focus on CLARREO Reflected Solar Instrument, specifically:
  - SI traceable benchmark measurement
  - Reference intercalibration
- Address Key Issues Critical to Achieving SDT Objectives
  - Liaisons with the broad science and applications community
  - Intercalibration assessments
  - Detailed, traceable uncertainty analysis

Approaches (1)

- Liaisons with the Broad Science Community
  - Provide guidance on instrument design, measurement requirements, calibration approaches, and L1 algorithm development, all while incorporating "lessons learned" from previous sensors (e.g. MODIS A&T, NPP/JPSS VIIRS, on next slides)
  - Participate in the science and user community conferences
    - SPIE (domestic and international), IGARSS, CALCON, AMS, and AGU, etc.
  - Engage agency and interagency missions and projects
    - EOS, NPP/JPSS, GOES-R, and other Decadal Survey missions…
    - Collaboration with NIST, NOAA, NASA/LaRC, NASA Ames, USGS…
  - Actively Support CEOS, GSICS, CGMS activities
    - 39th CGMS Meeting (October 2011)
    - CEOS IVOS Workshops (April 2011)
    - GSICS RWG (March 2011)
    - GSICS Executive Panel Meeting (June 2011)

MODIS Instrument



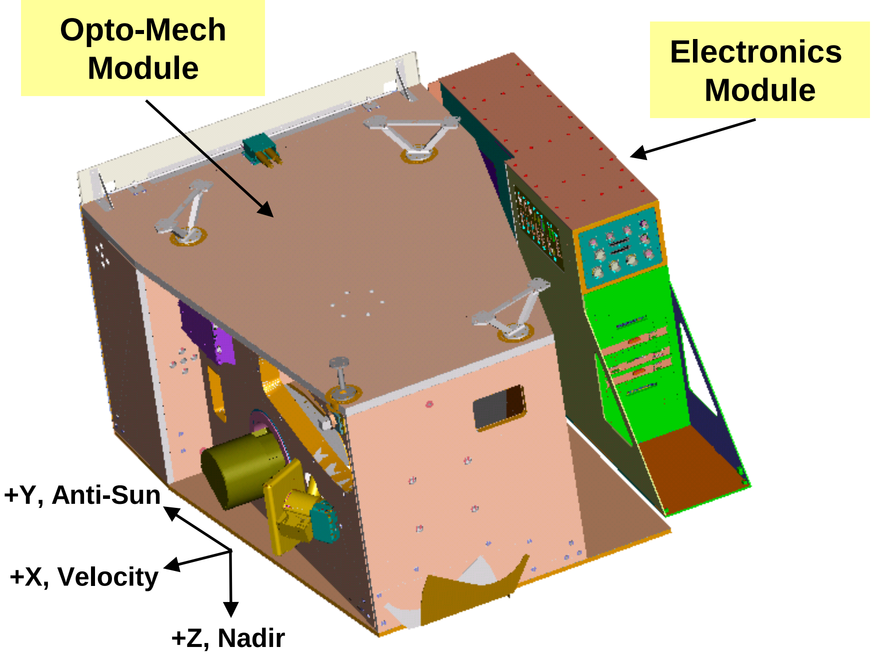
Terra

Aqua

- 20 Reflective solar bands (RSB): 0.41-2.2μm
- 16 Thermal emissive bands (TEB): 3.7-14.4μm
- 3 spatial resolutions at nadir: 250m, 500m and 1000m
- 4 Focal Plane Assemblies (FPA): VIS, NIR, SMIR, LWIR
- 5 On-Board Calibrators: SD, SDSM, SRCA, BB, and SV port

VIIRS Instrument

- **Multi-spectral crosstrack scanning instrument**
  - Rotating telescope
  - Half angle mirror (HAM) for de-rotation
- **Imagery and radiometry**
  - “Fine” (imaging) 0.4km resolution (nadir)
  - “Moderate” (radiometry) 0.8km resolution
- **22 spectral bands (0.4–12.5µm)**
  - 15 “reflective” VNIR-SWIR bands 0.4-2.3µm
  - 3 “mixed” MWIR bands 3.5 -4.1µm
  - 4 “emissive” LWIR bands 8.4-12.5µm
  - Automatic dual VNIR & triple DNB gains
- **EDR-dependent swath widths**
  - 1700, 2000, and 3000 km



Completed observatory level TV testing
Scheduled for launch in October 2011

Heritage Sensors: MODIS, SeaWiFS, THEMIS, TRMM VIRS, ETM+

MODIS Pre-launch Calibration

- Radiometric
  - Calibration source: SIS-100 (NIST traceable) at multiple radiance levels (lamp configurations)
  - Calibration parameters: gain, nonlinearity, SNR, dynamic range, gain dependence on the instrument temperatures
  - Three instrument temperatures for thermal vacuum test
  - Primary and redundant electronics
  - Solar diffuser BRDF calibration (NIST traceable)
- Other system-level characterization efforts
  - Spectral: relative spectral response (RSR)
  - Spatial: pointing, band-to-band registration (BBR)
  - Response versus scan angle (RVS)
  - Polarization sensitivity

VIIRS Pre-launch Calibration

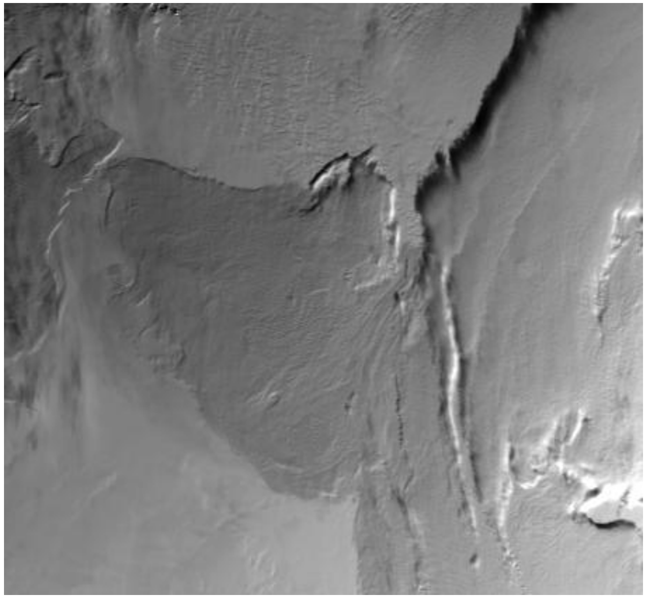
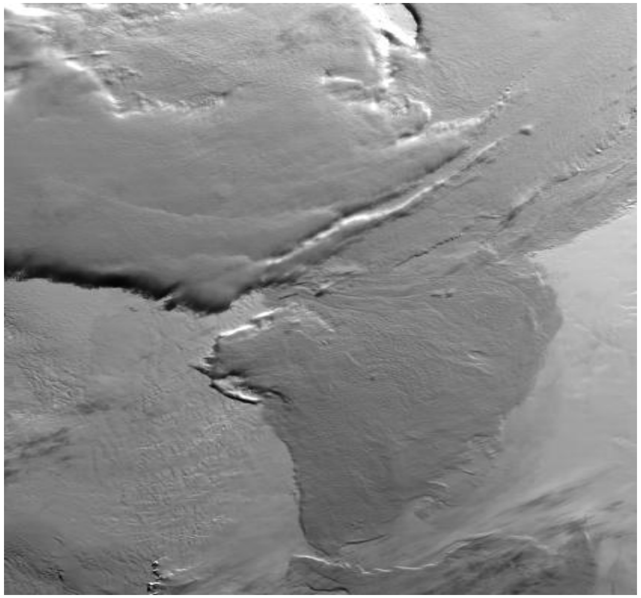
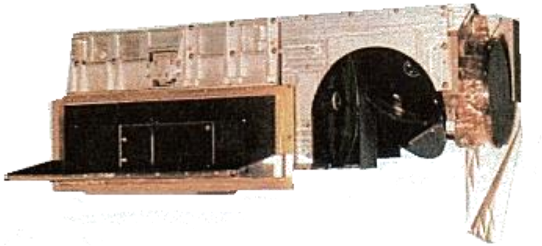
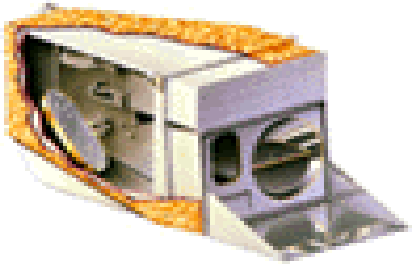
- Similar to MODIS
- Experience and lessons from MODIS
  - Polarization characterization (PSA and polarization sheet)
  - SIS stability monitor
  - Pathfinder RSB end-to-end (E2E) test
  - T-SIRCUS (i.e. laser-based) measurements of absolute and relative spectral response
  - Improved SD attenuation screen

NPP Scheduled to Launch in October 2011

Approaches (2)

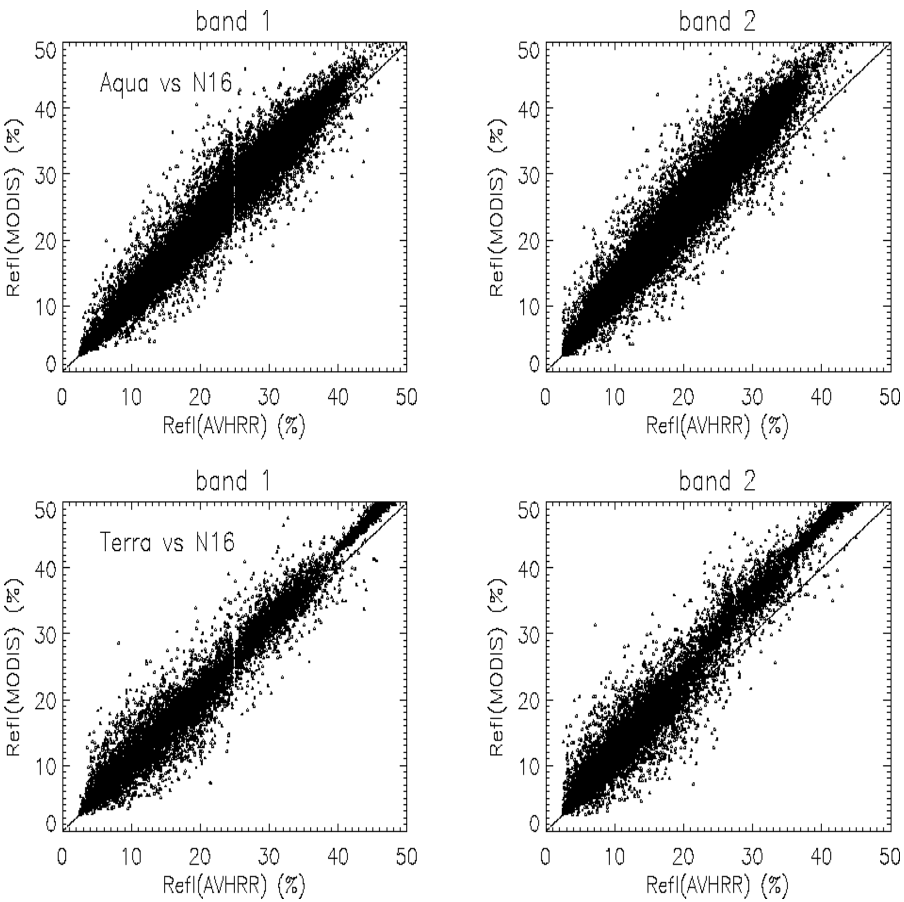
- Intercalibration Assessments
  - Identify candidate sensors and CEOS-endorsed reference sites for CLARREO intercalibration study
    - MODIS, AVHRR, VIIRS, …
    - Dome C, desert sites, Moon, …
      http://calval.cr.usgs.gov/sites_catalog_ceos_sites.php
  - Evaluate RS intercalibration methodologies
    - SNO, lunar calibration, observations versus model predictions
    - Collaboration with NOAA (C. Cao), USGS (T. Stone), NASA/LaRC (D. Doelling and C. Lukashin)

Inter-comparison of MODIS and AVHRR using SNO

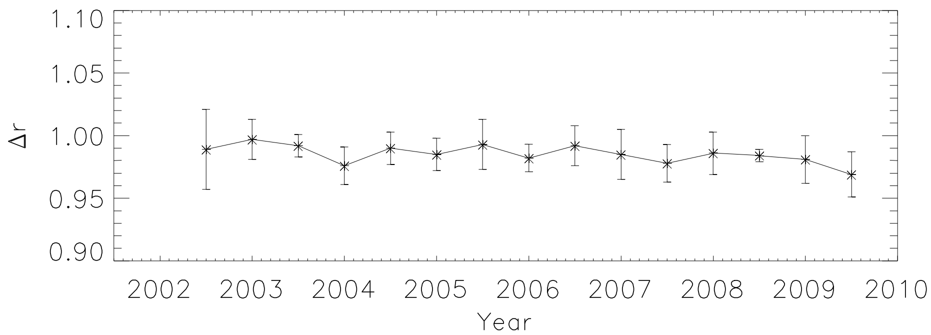





An SNO image pair from MetOp-A AVHRR channel 1 (left) and Aqua MODIS band 1 (right) acquired on 13 December, 2006 (2006347.2345)

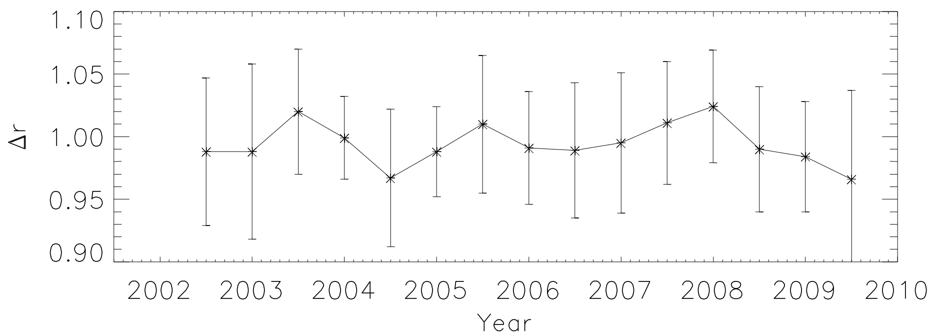
Inter-comparison of MODIS and AVHRR using SNO



Band 1 (0.65 μm)



Band 2 (0.85 μm)



More spectral band pairs for MODIS and VIIRS calibration inter-comparison

Xiong et al., "Progress and Lessons from MODIS Calibration Inter-comparison Using Ground Test Sites" CJRS 2011

The Moon as an On-orbit RSB Cross-comparison Target for MODIS and other Sensors: Results and Lessons Learned

- Examined the use of lunar views in the cross-comparison of MODIS (A&T) with SeaWiFS (from Eplee, R.E., et al., "Cross calibration of SeaWiFS and MODIS using on-orbit observations of the Moon," Appl. Optics, 50, 120-133 (2011).
- Will extend the application of lunar views at shortwave ir wavelengths

SeaWiFS Band No.	Wavelength (nm)	Bandwidth (nm)	MODIS Band No.	Wavelength (nm)	Bandwidth (nm)
1	412	402-422	8	412	405-420
2	443	433-453	9	443	438-448
			3	469	459-479
3	490	480-500	10	488	483-493
4	510	500-520	11	531	526-536
5	555	545-565	12	551	546-556
			4	555	545-565
6	670	660-680	1	645	620-670
			13*	667	662-672
			14*	678	673-683
7	756	745-785	15*	748	743-753
8	865	845-885	2	858	841-876
			16*	869	862-877

*MODIS bands that saturate on the Moon

SeaWiFS and MODIS Lunar Observational History

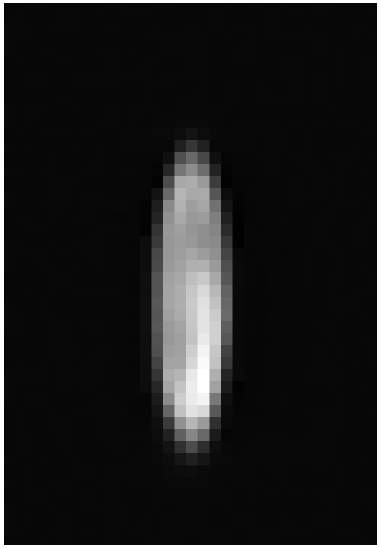
Sensor	Lunar View Type	Lunar Phase Angle	Number of Views	Time Range
SeaWiFS	Low phase: -7 to +7 deg. nominal Cross-calibration High phase	-6 to 8 deg., +5 to +10 deg. -27.1 deg. -27 to -49 deg., +27 to +66 deg.	83, 49 (38[a]) 1 26, 32	Nov. 97-Apr. 09 14 Apr. 03 at 22:34:21 UT Jul. 04-Dec. 07
Terra MODIS	Scheduled: +55 deg. Nominal Cross-calibration Unscheduled	+52 to +62 deg. -27.7 deg. +55 to +82 deg.	82 (73[b]) 1 297	Mar. 00 –Feb. 09 14-Apr. 03 at 22:09:35 UT Jul. 00- Dec. 08
Aqua MODIS	Scheduled: -55 deg. Nominal Unscheduled	-51 to -58 deg. -54 to -80 deg.	61 (50[d]) 171	Jun. 02-Apr. 09 Dec. 02-Dec. 08

[a]SeaWiFS lunar views between +6 and +8 deg.

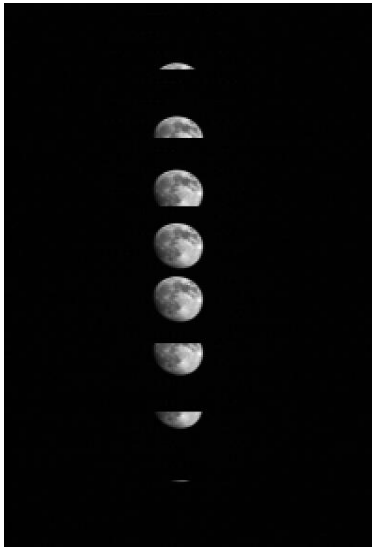
[b]Terra lunar views between +54 and +56 deg.

[c]Aqua lunar views between -54 and -56 deg.

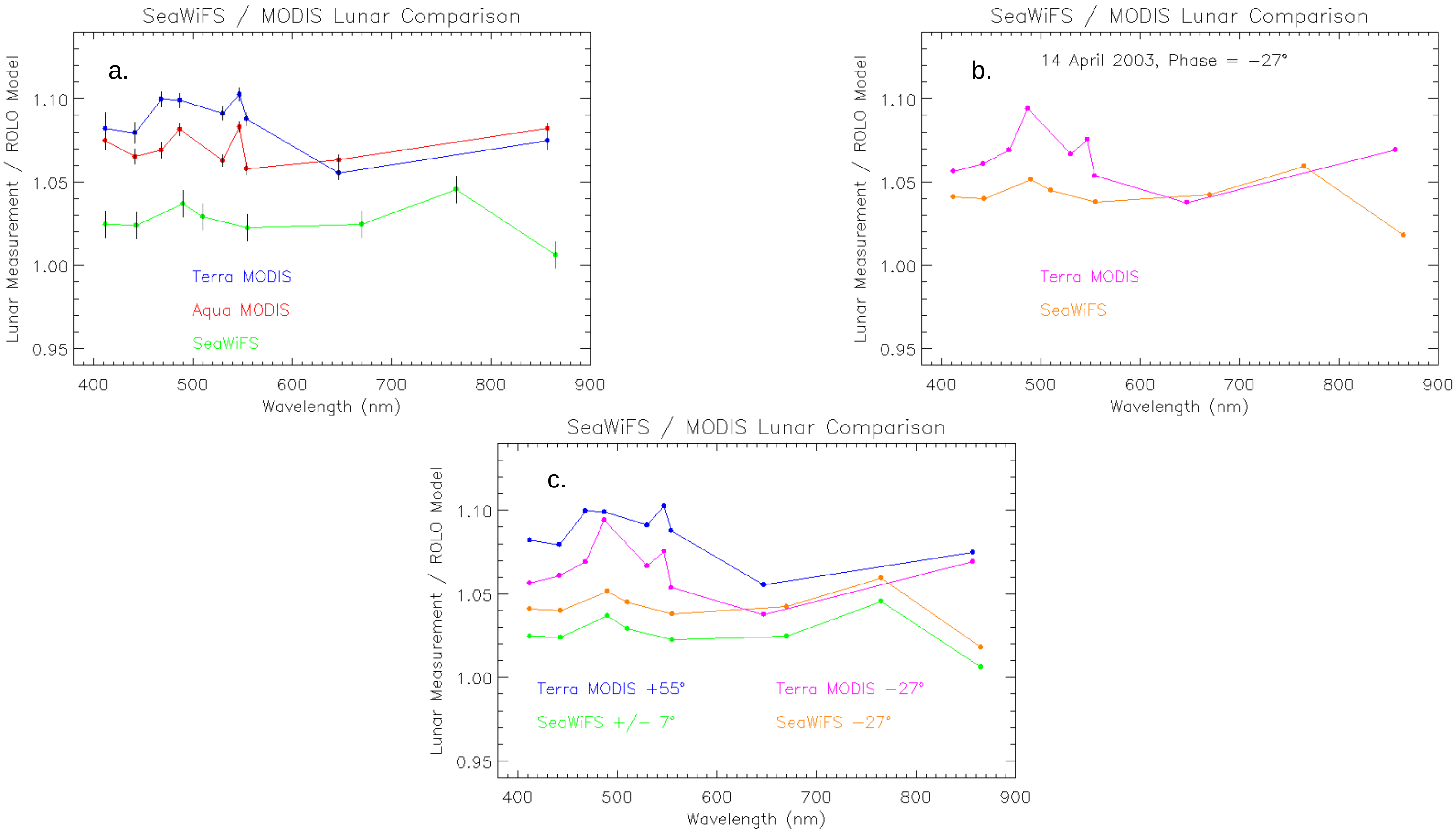
SeaWiFS 412 nm band



MODIS Terra 645 nm band



SeaWiFS/MODIS Lunar Comparisons

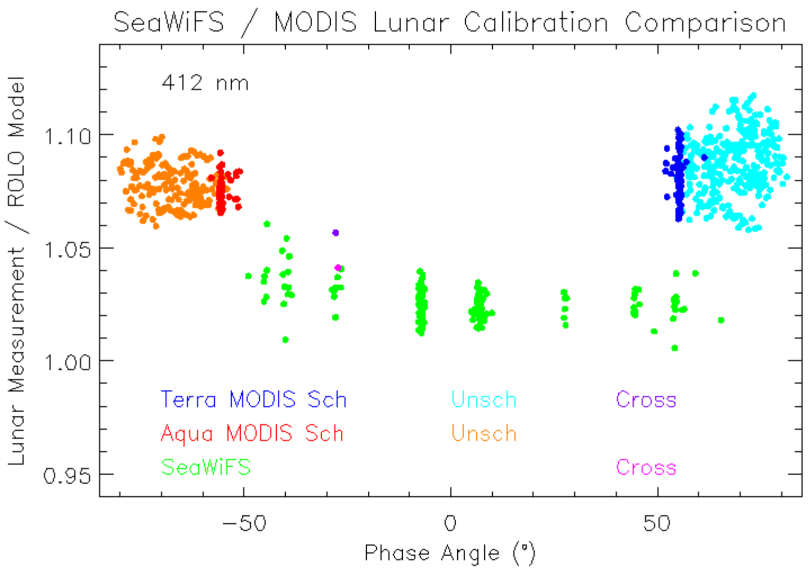


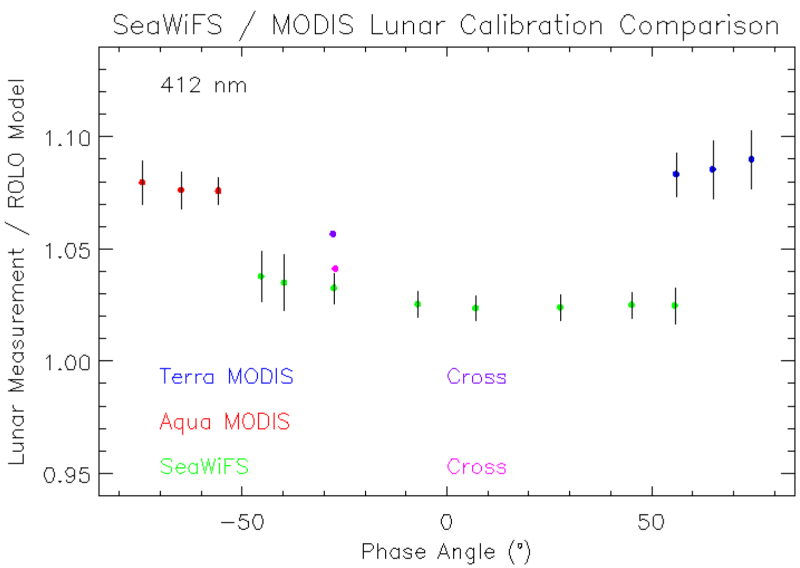
Mean Uncertainty of Terra/Aqua bias for all bands: 1.7 ± 1.3%
Mean Uncertainty of SeaWiFS/Terra bias for all bands: 5.9 ± 1.4%
Mean Uncertainty of SeaWiFS/Aqua bias for all bands: 5.0 ± 1.3%

Sources of uncertainty:

-Observational scatter in data (in a and b)
-Residual RVS error in SeaWiFS observations (0.3%) (in a and b)
-Residual phase dependence in lunar model (<1.7%) (in a)
-Residual RVS error in MODIS (in a and b)

Phase Dependence of the Lunar Model





- Inherent scatter in a series of lunar measurements at 412 nm (top plot)
  - SeaWiFS uncertainty primarily due to oversampling correction
  - MODIS uncertainty primarily due to lower lunar signal at higher lunar phase
- Binned residuals plotted as means with standard deviations at 412 nm (bottom plot)
  - Phase dependence (phase angle):
    - MODIS Aqua: 1.1% from -80 to -51 deg.
    - SeaWiFS: 1.7% from -45 to -6 deg. & 5 to 56 deg.
    - MODIS Terra: 1.5% from 52 to 82 deg.
- An uncertainty of 1.7% is a robust estimate of the lunar model phase dependence from -80 to -6 deg. and from 5 to 82 deg.
  - USGS estimate of lunar model phase dependence: 1% from a much larger database of lunar measurements from the ground

Approaches (3)

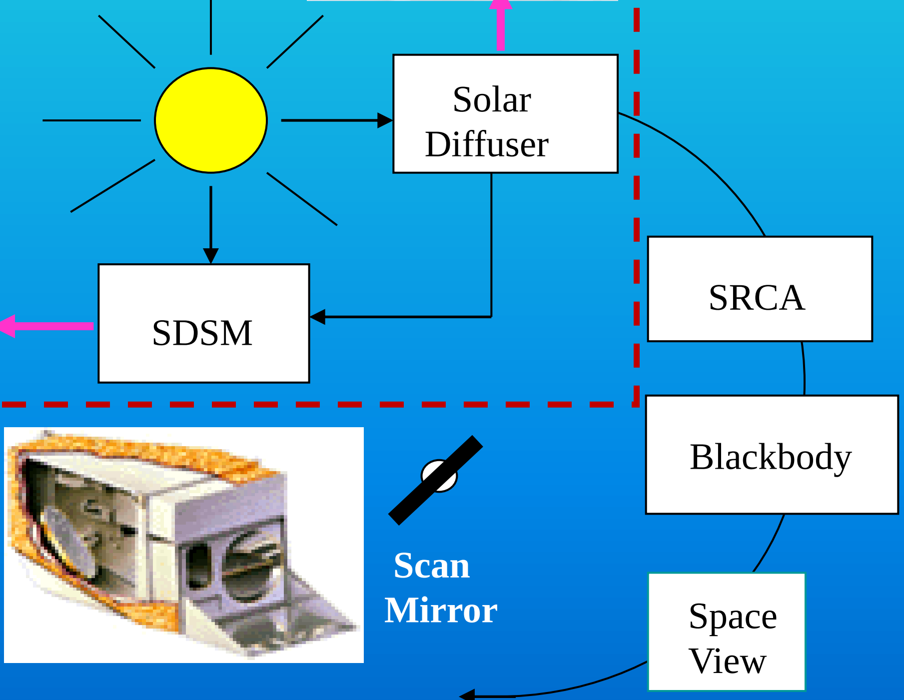
- Traceable Uncertainty Analysis
  - Provide guidance and recommendations for the development of CLARREO RS instrument calibration and validation plan
  - Perform detailed SI-traceable measurement uncertainty analysis for the proposed CLARREO RS instrument
    - Radiometric, spectral, and spatial performance
    - Component, subsystem, and system level
    - Pre- and post-launch
  - Design and develop an uncertainty analysis tool (utility) that can be adapted to comprehensively identify and quantify CLARREO RS instrument uncertainties
    - Approaches and lessons from MODIS and VIIRS
    - In accordance with NIST documents and recommendations

MODIS On-orbit Reflective Solar Calibration

EV Reflectance $$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$$

$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$

$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}}$$



Δ_{SD}: SD degradation factor;

Γ_{SD}: SD screen vignetting function

d: Earth-Sun distance

dn*: Corrected digital number

dc: Digital count of SDSM

MODIS BRF Characterization (traceability)

NIST Standard Reference → Lab Secondary Standard → MODIS SD BRF

Pre-launch

	Error Sources	SBRS
1	NIST reference:	0.50
2	SBRS scattering goniometer:	0.70
3	NIST BRF scale to MODIS SD reference:	0.50
4	MODIS SD characterization:	0.50
5	SD spatial non-uniformities:	0.70
6	Interpolation angular / spectrally:	0.10
7	Pre-launch to on-orbit SD BRF change:	0.50
8	SD screen (SDS):	0.20
9	SDSM and SDS impact:	0.50
10	Solar illumination of the SD surrounds	0.30
11	Earthshine through the SD door	0.30
12	Earthshine through nadir aperture door	0.10
	RSS	1.57

%

SD BRF characterized at limited wavelengths, angles, and panel locations

SBRS: Santa Barbara Remote Sensing

Reflectance Uncertainty Budget Components for a MODIS/VIIRS-like Instrument

Sensor Measurement Uncertainty

Instrument & SC Performance Uncertainties

Calibration & Algorithm Uncertainties

·**Optics:**
- -RSR uncertainty
  - -Uniform calibration source
  - -In-band characterization
  - -Out-of-band characterization
  - -λ stability (transmission Δ's, contamination, ageing, T effects)
  - -BW stability (transmission Δ's, contamination, ageing, T effects)
- -Stray light
  - -Far-field, off-axis scattered light
  - -Near-field, structured scene scattered light
  - -Earthshine thru EV port
- -Optical crosstalk & ghosting
- -Polarization responsivity
- -RVS uncertainty
- -Optical alignment, jitter, & T effects

·**Detectors:**
- -Readout noise
- -Temperature stability
  - -Short term (within and between orbits and calibrations)
  - -Long term (within and between seasons and over the mission)
- -Dynamic crosstalk
- -Pre-launch detector characterization
  - -Responsivity uncertainty
  - -Dynamic range uncertainty
  - -Linearity uncertainty
  - -Stability
- -On-orbit detector inherent performance
  - -Responsivity stability (short and long term)
  - -Dynamic range stability
  - - Linearity stability
  - -Degradation (transmission Δ's, contamination, ageing)

·**Electronics**
- -Random noise
- -Temperature effects
- -Differential non-linearity from A/D
- -Quantization (round-off) uncertainties
- -Static crosstalk

·**Pointing and geolocation uncertainties**

·**Calibration:**
- -Solar diffuser uncertainty
  - -BRDF characterization uncertainty
    - -Pre-launch
    - -On-orbit (short and long-term)
  - -Solar diffuser illumination angle uncertainty
  - -Solar diffuser view angle uncertainty
  - -Solar diffuser on orbit assembly temperature and performance
  - -Stray light contamination effects
    - -Earthshine
    - -Solar diffuser surrounds
- -Solar diffuser screen uncertainty
  - -Screen characterization errors
  - -Screen illumination modulation
  - -On-orbit thermal/optical performance
- -Solar diffuser stability monitor uncertainty
  - -SDSM band responsivity characterization
  - -SDSM and sensor band mismatch uncertainty
  - -SDSM measurement uncertainty in sun view vs. solar diffuser view
  - -SDSM electronics digitization (A/D) uncertainty
  - -Short and long-term optoelectronic stability of SDSM

·**Algorithms:**
- -Intrinsic errors in algorithms
- -LUT entry errors
- -Auxiliary data errors

·This uncertainty budget is being adapted for the case of the CLARREO RSB instrument (i.e. reflectance-based , attenuated (e.g. apertured) direct solar view).

"The exact procedures and ultimate realizable uncertainties in the calibration of an instrument depend on instrument details and how the instrument will be used."

"The quality of a calibration depends primarily on the familiarity of the instrument operator with all the details of his/her instrument and his/her dedication to accuracy and thoroughness."

Fred Nicodemus & George Zissis, October 1962

Key Documents


JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

First edition September 2008

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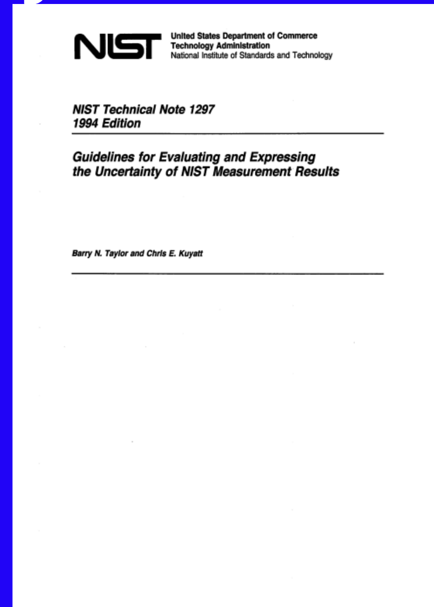
Guide to the Expression of Uncertainty in Measurement (GUM) JGCM 100-2008


NIST United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

NIST Technical Note 1297
1994 Edition

Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results

Barry N. Taylor and Chris E. Kuyatt

Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results NIST TN1297


INTERNATIONAL STANDARD

ISO 5725-1

First edition 1994-12-15

Accuracy (trueness and precision) of measurement methods and results —
Part 1:
General principles and definitions

Exactitude (justesse et fidélité) des résultats et méthodes de mesure — Partie 1: Principes généraux et définitions

Reference number ISO 5725-1:1994(E)

Accuracy of Measurement Methods and Results: Parts 1 to 6 ISO 5725-1 to 6


JCGM 200:2008

International vocabulary of metrology — Basic and general concepts and associated terms (VIM)

Vocabulaire international de métrologie — Concepts fondamentaux et généraux et termes associés (VIM)

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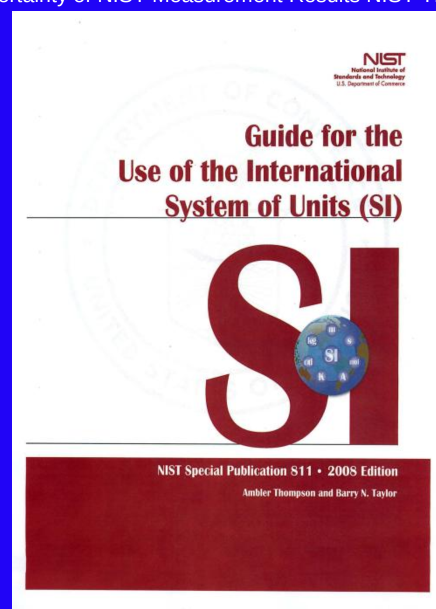
International Vocabulary of Metrology (VIM) JGCM 200-2008

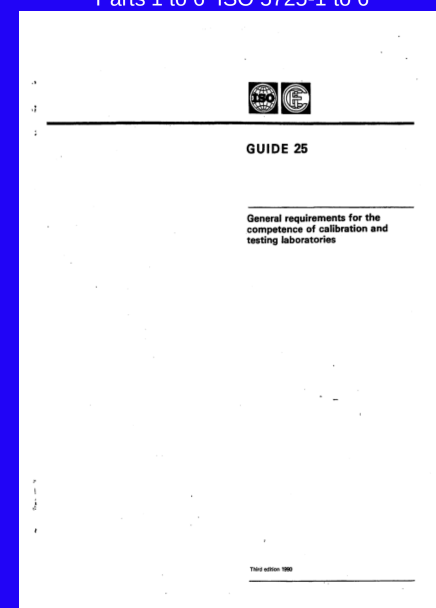

NIST National Institute of Standards and Technology U.S. Department of Commerce

Guide for the Use of the International System of Units (SI)

NIST Special Publication 811 • 2008 Edition

Ambler Thompson and Barry N. Taylor

Guide for the Use of the International System of Units (SI) NIST SP811


GUIDE 25

General requirements for the competence of calibration and testing laboratories

Third edition 1990

General Requirements for the Competence Of Calibration and Testing Labs ISO Guide 25

Timeline and Deliverables (Year 1)

- Identify candidate instrument design and pre-launch calibration and characterization approaches for the CLARREO RS instrument.
- Identify, for each candidate instrument hardware design, the complete suite of subsystem level characterization measurements required as part of acceptance testing; quantify, with respect to radiometric and spectral performance, the complete measurement uncertainties for these subsystem characterization approaches.
- Identify and examine candidate sensors and CEOS-endorsed reference sites for CLARREO IC study.
- Compare and evaluate different IC methodologies, and identify key uncertainty contributors to each approach.
- Present results of the above studies at CLARREO Science Definition Team Meetings, Technical Meetings, and in refereed publications.

Summary

- NASA GSFC's focus areas on science definition support for the CLARREO Reflected Solar Instrument include:
  - Instrument design and supporting analyses for the production of SI traceable benchmark measurements from CLARREO
  - Quantitative assessments of the the use of CLARREO data in reference intercalibration activities
  - Production of detailed, SI traceable, CLARREO specific uncertainty analyses
  - Nurturing existing and establishing new liaisons with the broad science and applications communities

Flexible in support of SDT activities in light of recent changes

Backup Slides

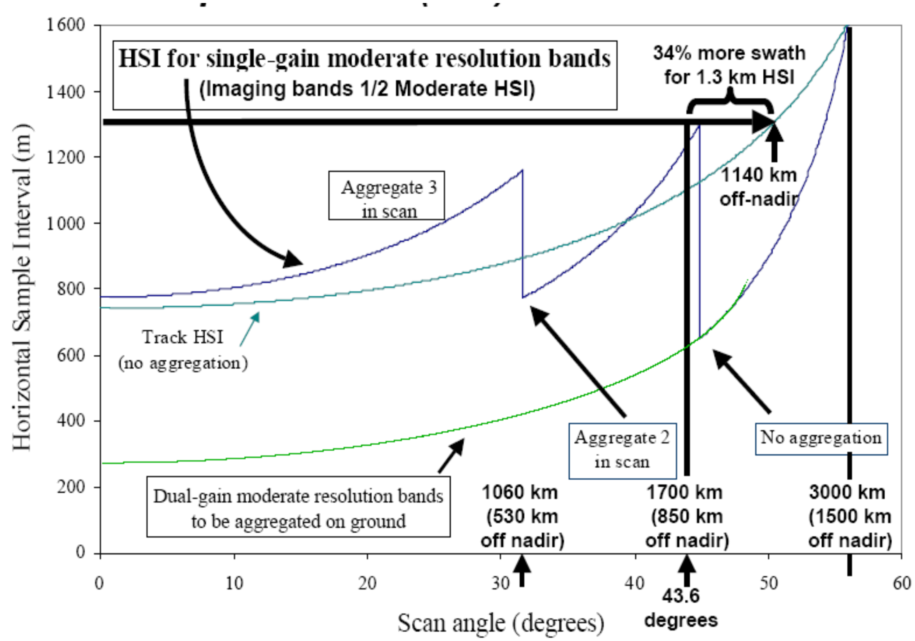
MODIS and VIIRS

VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
○ M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
○ M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
○ M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
○ M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
○ M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
○ M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
○ M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

○ **Dual gain band**

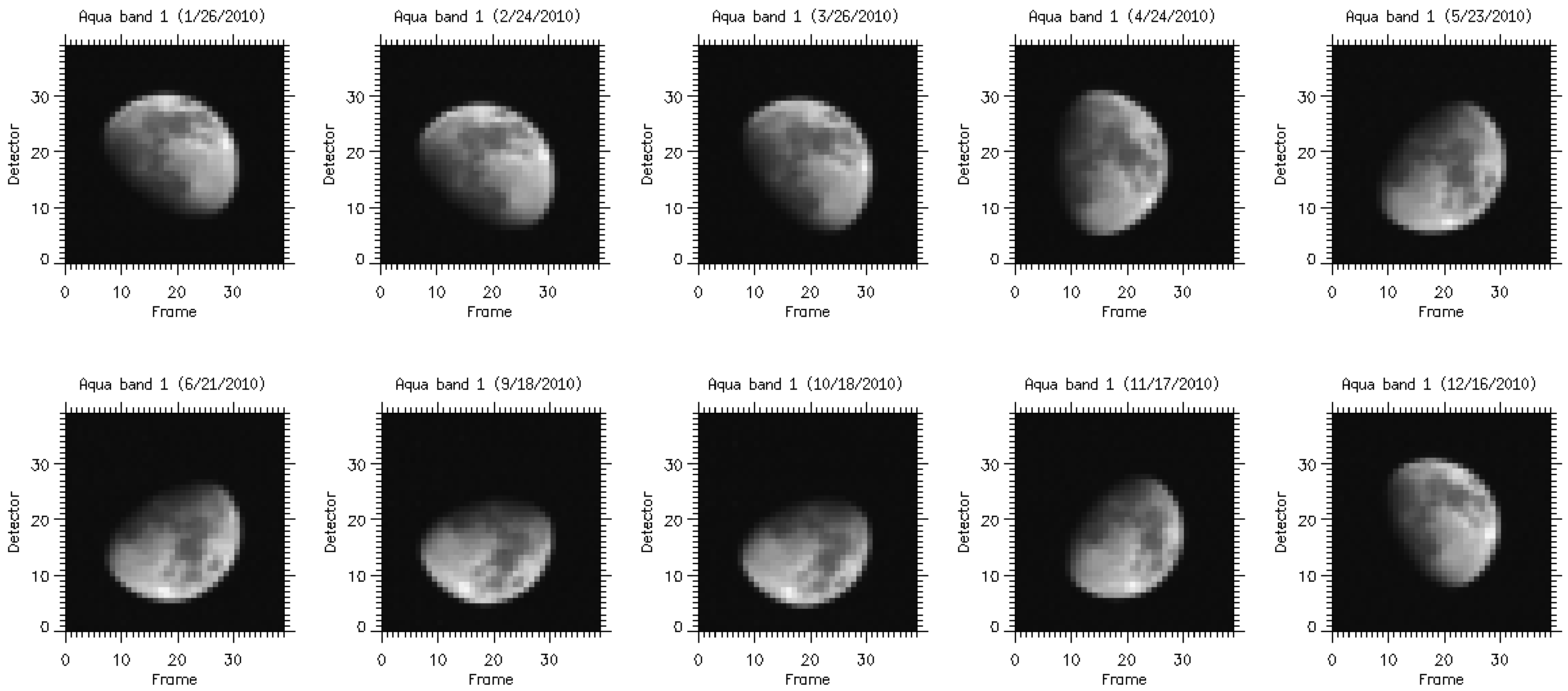
Changes from MODIS

- Use of a Telescope instead of rotating mirror
- Use of dual gain bands
- Removed CO2 bands
- Deleted Spectro-Radiometric Assembly
- Added pixel aggregation
- Guaranteed End-Of-Life Performance Spec
- Solar Diffuser Screen with Earthshine shade



MODIS Lunar Observations

- MODIS lunar observations are scheduled near-monthly at fixed phase angles for each instrument via S/C roll maneuvers; Moon is viewed through instrument space view at a fixed AOI
- Examples of Aqua MODIS lunar images acquired in 2010



The Moon as an On-Orbit Comparison Target: Lessons Learned

- Require a totally maneuverable s/c with ACSs that provide and maintain accurate knowledge of s/c pitch/roll rates during lunar views.
- Accurately account for oversampling of the Moon for those instruments where the pitch rate of travel over the Moon is slower than the instrument scan rate.
- Plan for the maximum number of lunar observations to reduce scatter in the observational dataset.
- Plan to view Moon through the earth view port. If not possible or infrequent, require high accuracy RVS measurements of scanning optics.
- Plan to cross-compare instruments looking at the same lunar phase. For those situations where this is not possible, carefully account for differences and resultant increased uncertainties in time/lunar phase and instrument lunar data if this is not possible.
- Choose a lunar phase that avoids the opposition effect but still maximizes lunar S/N.
- Design instrument so that RSB bands do not saturate on the Moon.

If lunar measurements are carefully and optimally performed, instrument on-orbit comparisons better than 1% should be realizable.

Inter-comparison of MODIS and other Sensors using SNO: Lessons Learned

- Importance of sensor calibration traceability
  - Sensor on-orbit calibration (standard) reference
  - Knowledge of sensor calibration uncertainties
- Knowledge of sensor characteristics
  - Relative spectral response (RSR)
    - Scene dependent corrections
  - Nonlinearity
    - Scene reflectance (radiance) level dependency
  - Impact due to polarization sensitivity
    - Surface type (polarization) and solar angle dependent impact (critical to polarization sensitive spectral bands)
  - Temporal stability
    - Important for long-term inter-comparisons and statistics